Energy Research and Development Division
FINAL PROJECT REPORT

Data Center Energy Efficiency and Demonstration Projects

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PREFACE

The California Energy Commission Energy Research and Development Division supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The Energy Research and Development Division conducts public interest research, development, and demonstration (RD&D) projects to benefit California.

The Energy Research and Development Division strives to conduct the most promising public interest energy research by partnering with RD&D entities, including individuals, businesses, utilities, and public or private research institutions.

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- Renewable Energy Technologies
- Transportation

Data Center Energy Efficiency and Demonstration Projects is the final report for the Data Center Energy Efficiency and Demonstration Project (contract number 500-09-002) conducted by Lawrence Berkeley National Laboratory. The information from this project contributes to Energy Research and Development Division's Industrial/Agricultural/Water End-Use Energy Efficiency Program.

For more information about the Energy Research and Development Division, please visit the Energy Commission's website at www.energy.ca.gov/research/ or contact the Energy Commission at 916-327-1551.

ABSTRACT

The Data Center Energy Efficiency and Demonstration Projects focused on research and demonstrations of energy efficiency strategies to improve the energy performance of data centers. The project included development of proposed Leadership in Energy and Environmental Design™ criteria for use with existing data centers, comparison of modular cooling systems used in data centers, a demonstration on the use of direct current power distribution, a demonstration of alternative cooling for data centers, and collaboration with the Silicon Valley Leadership Group in its annual Data Center Summit, which showcases data center demonstrations.

Proposed Leadership in Energy and Environmental Design™ criteria for existing data centers emphasized energy and water use credits and de-emphasized other sustainability credits that are relatively less important for these buildings.

Evaluations of modular cooling systems involved a significant commitment by industry partners that supplied the systems for evaluation and hosted their installation in an operating data center. The study concluded that these systems perform better than standard practice.

Industry collaboration to promote the use of direct current power distribution in data centers continued with a demonstration hosted by the University of California, San Diego in a containerized data center. This demonstration utilized direct current connectors, power supplies, and a rectifier supplied from industry partners. The demonstration confirmed that the industry is making progress in standardizing and product development. Power savings were observed when compared to typical alternating current system design.

An alternative cooling technology for use in data centers was demonstrated. This system involved a novel heat transfer methodology using conduction and convection to remove heat from information technology equipment components, which allowed removal of equipment fans and used efficient heat transfer to a refrigerant. The technology was much more efficient than current practice.

Keywords: California Energy Commission, High-tech buildings, data centers, DC Power, LEED criteria, modular cooling, SVLG, data center efficiency

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Introduction

Energy intensive data centers are common in California and are found in virtually every company. A large computing presence exists in web-based firms, banking, entertainment and virtually every other industry. Academic institutions, defense facilities, national laboratories, and other federal and state agencies also operate large data centers. Data centers typically operate continuously and have large, continuous electrical demand with far higher energy intensities (energy per unit of floor area) than conventional buildings.

This project continued research and demonstrations to advance the understanding of energy efficiency improvements that are available for data centers. Selective research and demonstration projects supporting areas identified in the data center research roadmap were completed in earlier PIER projects and this project continued to focus on additional strategies from the research roadmap.

Project Purpose

The primary goal of this project was to perform high-priority research and demonstrations of new or underutilized technologies that could lead to energy efficiency improvements of at least 40 percent. These technologies were identified in the PIER "Data Center Energy Research Roadmap."

The objectives for meeting these goals included:

- Developing case studies and best practice information.
- Developing more appropriate Leadership in Energy and Environmental Design (LEED)™ type criteria for use in data centers.
- Evaluating technologies to determine their energy efficiency.
- Dispelling concerns over the use of air economizers in data centers.
- Demonstrating new or emerging technologies for use in data centers.
- Partnering with the Silicon Valley Leadership Group (SVLG) and engaging their high-tech member companies.
- Disseminating energy efficiency information to as wide an audience as possible.

Project Results

Some of the more significant achievements described in this report include:

- Participation in the 2010 SVLG demonstration study culminated in a workshop attended by over 500 high-tech professionals.
- Co-leadership of the 2010 SVLG demonstration projects enabled the SVLG/PIER partnership to demonstrate leadership in the high-tech field. Additional high-value demonstrations were identified through interaction with industry and resulted in case studies that were presented at the SVLG Data Center Summit (http://greensvlg.org/data-center-efficiency-summit/agendas-presentations/2010-2).

- Proposed LEED™ criteria for existing data center facilities were developed for the U.S. Green Building Council. The proposed criteria were peer reviewed by all of the major data center organizations and evaluated by the U.S. Green Building Council for inclusion in the LEED™ rating criteria.
- Information technology (IT) manufacturers have reported equipment failures when data center equipment is operated in harsh, polluted environments. This project conducted tests on the effects of gaseous contamination on IT equipment at various sites around the country and found that no centers reported equipment failures due to contamination.
- A comparison of commercially available modular cooling systems used to cool racks of computers showed that such cooling devices were much more efficient than standard practice.
- Direct current (DC) power distribution for data centers was further developed and demonstrated. The project team collaborated with over 30 industry leaders in the United States, Japan, and Europe to develop a world-wide standard. The industry team joined ranks with Emerge Alliance, a non-profit industry association advocating DC power solutions. Emerge Alliance agreed to help promote higher voltage (380 volt) DC by developing standards and conducting outreach.
- A novel server cooling strategy developed by Clustered Systems was extremely efficient at heat removal and this system could allow cooling of IT equipment without the use of compressor-based cooling such as chillers.
- Numerous training and outreach workshops given at various venues in California reached a large number of data center professionals and utility representatives.
- An extensive amount of material was published on the Lawrence Berkeley National Laboratory (LBNL) website, including individual task reports and presentation materials (http://hightech.lbl.gov). Additionally, articles in trade publications, and professional journals were published. The project included active participation in industry technical committees or standard-setting groups including ASHRAE, 7x24 Exchange, Uptime Institute, SVLG, Critical Facilities Roundtable, the Green Grid, and Darnell.

The research and demonstrations conducted in this project illustrated that there are numerous energy efficiency strategies that can improve the efficiency of data center facilities. Energy efficiency opportunities resulting in 20-40 percent energy savings were demonstrated, which is consistent with prior investigations. The authors recommended that PIER continue to support data center research and demonstrations since the market is growing and the energy savings potential is high. PIER should also consider establishing a center for high-tech facility research, development and demonstration because these facilities are crucial to California's economy. Collaboration should continue with major industry organizations such as the Silicon Valley Leadership Group to accelerate the adoption of energy efficient strategies and technologies.

Project Benefits

This project helped advance technologies that could increase energy efficiency in California. Increased energy efficiency will reduce overall energy use, which will in turn reduce greenhouse gas emissions and other emissions that cause air pollution.

Chapter 1: Introduction

Energy intensive data centers are common in California and are found in virtually every company. A large computing presence exists in web based firms, banking, entertainment and virtually every other industry. Academic, Defense, National Laboratories, and other Federal and State agencies also operate large energy intensive data centers. The energy use of these facilities is large and growing.

This project continued research and demonstrations to advance the understanding of energy efficiency improvements that are available to this market. Selective research and demonstration projects supporting areas identified in the data center research roadmap were completed in earlier PIER projects and this project continued to focus on additional strategies from the research roadmap.

The project reported here included activities focused solely on data center facilities. The project enabled collaboration with one of the nation's leading high-tech industry associations, the Silicon Valley Leadership Group (SVLG). In this collaboration, LBNL represented PIER in working with SVLG member companies to develop and then publicize data center demonstration projects. LBNL helped organize and participated in a data center "Summit" hosted by SVLG where the member companies, and LBNL, reported on various energy efficiency projects.

This report is organized such that each task is addressed in summary fashion in the body of the report where task numbers correspond to the contract task numbers. Detailed stand-alone reports and supplemental materials for some of the tasks were prepared and are attached as appendices to this overall project report. See the Appendix summary for task and appendix number correlation. These collectively constitute the final report deliverable for the project.

Chapter 2:
Project Objectives

This project included objectives in the following areas:

- Continue to follow the PIER data center research roadmap
- Develop case studies and best practice information
- Develop more appropriate LEED™ type criteria for use in data centers
- Evaluate technologies to determine their energy efficiency
- Dispel concerns over the use of air economizers in data centers
- Demonstrate new or emerging technologies for use in data centers
- Partner with the Silicon Valley Leadership Group and engage their high-tech member companies
- Disseminate energy efficiency information to as wide an audience as possible

Specific objectives for the various tasks are described below.

The objective of the following tasks was to perform high priority research and demonstrations of new or underutilized technology as identified in the PIER "Data Center Energy Research Roadmap" to develop or demonstrate solutions that could lead to 40 percent or more energy efficiency improvement. The objectives for the individual activities are detailed below:

Task 2.1 SVLG and PIER Data Center Demonstration Leadership

LBNL represented the PIER program in collaboration with the Silicon Valley Leadership Group (SVLG) to organize a series of demonstration projects with the objective of encouraging SVLG member companies to implement energy efficiency measures in their data centers. The member companies were encouraged to implement one or more efficiency measure(s) and then report on the measure(s) at the annual SVLG "Data Center Summit". Reporting on the demonstrated technology to the industry has been an effective method of promoting adoption of data center efficiency measures. LBNL's role was to provide planning support and provide technical input and recommendations for potential demonstration areas to SVLG member companies.

LBNL also investigated other technologies that could be appropriate for PIER demonstration projects. The objective was to identify additional new or underutilized technologies for possible future demonstrations.

A description of the SVLG program can be found here: http://greensvlg.org/data-center-efficiency-summit

The PIER sponsored modular cooling evaluation (Task 2.4), the DC power demonstration (Task 2.6) and the alternative cooling demonstration (Task 2.5) were included in the SVLG group of demonstration projects.

Task 2.2 Develop LEED™ type proposed criteria for rating existing data centers

Similar to a prior PIER project task that developed recommended new LEED™ criteria for use in new construction, this task focused on developing recommended criteria for existing data center facilities. Currently the U.S Green Building Council's LEED™ certification program uses a point based system which assigns points for various sustainable design criteria. This point system was developed primarily to apply to commercial buildings to acknowledge sustainability. The current criteria do not adequately reflect the importance of energy and water use in energy intensive data center facilities. Because the rating criteria have gained in popularity, there is a desire by industry to apply the LEED™ criteria to data center facilities. The objective of this task was to develop draft criteria in collaboration with data center industry associations to ensure broad consensus for the recommended criteria. The draft criteria were then submitted to the USGBC for their consideration.

During the period of this project, the U.S. Green Building Council established a committee of industry experts to consider revisions to the LEED™ criteria specifically for data centers. Steve Greenberg (LBNL) and Ray Pfeifer (LBNL subcontractor) participated in this committee.

To evaluate the criteria, an objective was included to determine how the criteria would be used in practice by trial in one or more data center.

Task 2.3 Research related to use of air economizers

The objective of this task was to encourage the use of air economizers in data centers by overcoming barriers to the use of outside air. Air economizers, which bring in large amounts of outside air to cool internal loads when weather conditions are favorable (as they are in many California climates), could save energy for cooling. However, there is reluctance from many data center operators to use this common cooling technique due to fear of equipment damage from introducing outside air pollutants which over time could cause equipment failures. Prior studies focused on the ability to remove particulate matter through filtration. These studies confirmed that control of particulates should not be a problem for data centers. The industry then raised a concern over gaseous contamination causing damage to electronic equipment. The objective of this task was to provide additional understanding of the effects of gaseous contamination and, explore ways to monitor to detect if contamination is occurring.

Task 2.4 Modular data center equipment evaluations

The objective of this task was to assess the thermal and energy performance of commercially available modular cooling systems used for cooling racks of computers in data centers. This was a second phase to a project termed the "chill-off". Chill-off 2 evaluated additional modular cooling solutions and also tested their ability to cool with higher temperatures.

The design of traditional ventilation and cooling systems for data centers are typically less than optimal. Many manufacturers are now offering alternative cooling solutions that provide supplemental cooling in racks or rows of systems. Such pre-engineered systems could be a significant improvement over current design practice; however, without an energy focus, they could also lead to even lower energy efficiencies. The objective of this task was to evaluate the energy and cooling performance of cooling products offered by various manufacturers – APC, Emerson-Liebert, Rittal, IBM – Vette, Knurr, and Oracle (previously Sun Microsystems) provided support for the evaluation in their data center in Santa Clara, CA.

Task 2.5 Demonstration of alternative cooling

For this demonstration, an alternative cooling technology developed by Clustered Systems, Inc. for use on energy intensive servers was demonstrated at Oracle's data center in Santa Clara, CA. The objective of this demonstration was to perform a comparison between a rack of traditionally cooled servers compared with a rack of servers that had been modified using the Clustered Systems technology. For this demonstration, Oracle provided the servers and the location for the demonstration in their Santa Clara, CA data center.

Task 2.6 Demonstration of DC Power for data centers

This demonstration continued efforts promoting the use of direct current (DC) electrical power distribution in data centers in collaboration with the Electric Power Research Institute (EPRI) and interested industry participants. UC San Diego hosted a demonstration of this technology in a container data center located at the UC campus in San Diego. The objective of the demonstration was to show how this technology can be used in a data center environment and compare energy use compared to traditional AC power. A further objective was to continue to move the market to develop standards (e.g. voltage, power quality, standard connectors, power supplies, etc.) to encourage adoption.

Task 2.7 Technology Transfer

The objective of the technology transfer activities was to convey the knowledge gained, the experimental results obtained, and the lessons learned to key decision-makers in the various facets of the data center industry. Targeted audiences included facility designers and operators, manufacturers and suppliers, utilities, policy makers, and other public interest organizations.

Chapter 3: Project Approach

3.1 Task 2.1 SVLG and PIER Data Center Demonstration

The approach for this task was to work with SVLG to plan the yearly "Data Center Summit" through a series of planning meetings and conference calls. K. C. Mares of LBNL provided technical input and worked with SVLG companies and others to define demonstration projects. There was considerable follow up with the participating companies to define demonstrations, assist in technical content, and ensure timely completion.

For the data center event, K. C. Mares served as the master of ceremony and provided major logistical support. LBNL also participated by presenting three projects described in this report.

3.2 Task 2.2 Develop criteria to be proposed for LEED™ type certification of existing data centers

To develop a proposed set of criteria for use in LEED™ certification of data centers, a working group was organized which included representatives from all of the major data center industry associations. This working group included representatives from Silicon Valley Leadership Group, ASHRAE TC 9.9, the Uptime Institute, the Critical Facilities Roundtable, Green Grid, and 7x24 Exchange. The approach involved first developing a draft set of criteria through a small group of industry experts and then disseminating this draft for formal review by the various organizations. Through a series of meetings and conference calls, proposed criteria were developed that provided increased emphasis on sustainable issues important to data centers – primarily energy and water use. The draft criteria was then reviewed and commented on by a large number of data center stakeholders. Comments were incorporated and a finalized draft criteria document was submitted to the US Green Building Council for review.

To assess the practicality of using the draft criteria the criteria was utilized at three diverse data centers and the data center operators were queried to determine their reactions and any shortcomings.

3.3 Task 2.3 Research related to use of air economizers

This project started with a literature review of studies relating environmental conditions and electronic equipment failures. The literature review identified that past significant investigations from the 1980's (Battelle) and others were not successful with finding root cause gaseous contamination mixtures that cause electronic equipment failures.

To help with finding the latest information and research on the subject of environmental contamination and electronic failures an industry advisory group of major IT equipment and component manufacturers provided project direction recommendations. The guidance and information obtained from this group were very valuable in developing the research approach and achieving the results.

The number of variables relating gaseous contamination to IT equipment failures is large and includes: gas types, mixtures of gases, combinations of gas concentrations, catalytic gases, temperature and humidity. In addition printed wiring board (PWB) materials and feature-size design rules change continuously. For example the Restriction of Hazardous Substances Directive (RoHS) was adopted in February 2003 by the European Union and this led to rules for electronic materials that caused lead based solder-based PWB materials to be phased out and replaced in some cases with silver-based materials. The combination of these variables made finding a single or simple multivariate root cause difficult.

The common way to determine the gaseous-caused corrosion risk in data centers is the "reactivity monitoring" method described in ANSI/ISA-71.04-1985. This method exposes a copper Corrosion Classification Coupon (CCC) to the environment for a month or more and analyzes the copper corrosion product thickness using cathodic/electrolytic reduction to classify the environment into one of four severity levels.

The research team decided to use the CCC method containing copper and silver coupons strips to survey 19 data center sites 10 of which were located in California and 2 additional sites in India with a goal to obtain an initial idea of the environmental corrosiveness present in typical data centers, using the most common measurement method.

The test coupons and their mounting is shown in Figure 1.

Figure 1: Picture of an Unexposed Corrosion Classification Coupon

A number of coupons containing one copper and one silver strip were deployed for 30 days in each data center. The survey is limited as it covers one 30 day period at each of 21 data centers between the dates August through November 2010. A more comprehensive survey should include measurements spanning at least a complete calendar year to account for seasonal changes and is suggested for further studies to account for seasonal changes that may affect the environment and therefore the corrosion rate of the coupons.

3.4 Task 2.4 Modular data center equipment evaluations

The approach in evaluating modular cooling systems was initially developed in a prior PIER project which was termed the "chill-off" evaluation. Similar testing plans were developed in conjunction with the manufacturers of the equipment and the host site (Oracle). Oracle staff assisted in the set up and testing and also provided servers to populate the computer racks in the modular systems.

Systems were evaluated for energy use and thermal performance for varying lengths of time and for various temperatures of chilled water in order to determine performance at elevated temperatures.

The findings were presented at the Silicon Valley Leadership Data Center Summit in November, 2010.

3.5 Task 2.5 Demonstration of alternative cooling

This demonstration involved evaluation of an alternative cooling technology developed by Clustered Systems. This technology is based upon cooling by conduction and does not rely on air movement to cool the hot electronic components. The approach in this demonstration was to compare the cooling effectiveness to standard practice. Oracle provided the servers for the demonstration as well as space in their Santa Clara, CA data center. Energy performance was monitored while the computer systems were operating in a controlled manner.

The results were presented in a ASHRAE conference paper and reported in Appendix E of this report.

3.6 Task 2.6 Demonstration of DC Power for data centers

This task involved continuation of previous PIER efforts to promote the use of DC power distribution in data centers. This demonstration showed how DC Power distribution could be implemented in a data center. The work was supported by a broad group of industry participants that had been involved in the earlier proof of concept demonstration. LBNL's subcontractor, the Electric Power Research Institute provided technical leadership for this demonstration. UC San Diego hosted the demonstration and provided in-kind support for the installation and monitoring during the demonstration as part of its "Green Light" project. Industry partners assisted in the design of the demonstration and supplied a rectifier, power supplies, connectors, and specially designed DC monitoring equipment.

3.7 Task 2.7 Technology Transfer

The approach to technology transfer activities was to utilize as many channels of communication as possible, with efforts tailored for distinct target audiences, in order to reach the largest number of stakeholders. This included:

- An extensive website where detailed technical information was presented and continuously updated and maintained
- Periodic newsletters distributed to large audiences
- Trade publications

- Video documentaries
- Journal articles
- Workshops with industry
- Collaboration with industry associations and professional societies
- Interim reports of findings
- Utility workshops/training
- Individual requests for information
- Interaction with PIER and SVLG
- Industry press releases

Chapter 4: Project Outcomes

Project findings for each task are summarized below and detailed task reports and related information is provided as appendices to the report.

4.1 Task 2.1 SVLG and PIER Data Center Demonstration

LBNL partnered with the SVLG to encourage the SVLG members to proceed with demonstration projects. As a result, there a number of case studies were presented at the 2010 Data Center Summit including three presentations by LBNL for projects described in this report. The full agenda for the Data center Summit is provided on the SVLG website: http://greensvlg.org/data-center-efficiency-summit/agendas-presentations/2010-2

LBNL presented results from the gaseous contamination study, DC Power Demonstration, and the modular cooling evaluations ("Chill-off 2").

4.2 Task 2.2 Develop criteria to be proposed for LEED™ type certification of existing data centers

A draft set of proposed LEED™ criteria to be applicable to existing data centers was developed by a small group of industry experts and then reviewed by the various organizations. The proposed criteria provided increased emphasis on sustainable issues important to data centers – primarily energy and water use. The draft criteria was then reviewed and commented on by industry at large. Comments from a large number of data center stakeholders were incorporated and the finalized draft criteria document was submitted to the US Green Building Council for review. This consisted of a set of draft criteria, called the environmental performance criteria, and an application guide. These documents are provided in Appendix B.

To assess the practicality of the EPC criteria, LBNL interviewed several data center end users and developers who used the draft EPC during the design, construction and commissioning of several new data centers in California, New York and Singapore.[1]

The three data centers were asked to identify the most significant differences in the 2011 draft EPC requirements as compared to the USGBC LEED 2009 new construction building rating system that had the most impact to their data center's energy and environmental performance. Following is a summary of the survey:

Large Investment Bank, New Jersey

- Energy efficiency performance requirements at part-load conditions
- Minimum energy performance of >10 percent ASHRAE 90.1 based upon Appendix G
- Impact of inclusion of electrical losses in energy performance
- Points weighting changes to energy and water vs. sustainable site and IEQ

[1] Centers outside of California were queried by LBNL's subcontractor, Ray Pfeifer through other synergistic projects

Large Colocation Data Center Operator, California

- Energy efficiency performance requirements at part-load conditions
- Impact of the inclusion of electrical losses in energy performance
- Real-time PUE energy metering requirements & benefit of controlling supply air temperature based upon inlet air temperature of data center IT equipment
- Points weighting changes to energy and water efficiency vs. sustainable site and IEQ

Large Colocation Data Center Operator, Singapore

- Energy efficiency performance requirements at part-load conditions
- Impact of the inclusion of electrical losses in energy performance
- Points weighting changes to energy and water efficiency vs. sustainable site and IEQ
- Real-time PUE energy metering requirements & benefit

The EPC included a requirement to model the energy use of the proposed cooling system design at 25 percent, 50 percent, 75 percent and 100 percent IT load design and to commission the data center at these same simulated load levels vs. the LEED 2009 N.C. requirement that is only based upon 100 percent design load.

Each of the respondents indicated that this requirement was extremely important because typically it takes 2-3 years or more before the data center gets to 75-90 percent of peak design load. However, since the USGBC LEED requirement is based upon the 100 percent design load the cooling infrastructure and electrical distribution systems as designed in the past operated less efficiently during the initial build-out phase of the data center.

By requiring their designer to model the systems performance at part load, they indicated that they needed to change their standard central plant design to better match the low cooling load requirements and equipment sizes to operate more efficiently at low cooling loads.

By using a combination of different size or VFD chillers and variable pumping and heat rejection systems they were able to still achieve the minimum part load PUE performance, albeit at higher first cost.

The requirement to also commission the data center infrastructure systems at these part load levels was also indicated by the respondents as being extremely valuable to their design team to validate the actual energy efficiency as well as to the operations team to correlate the on-going performance of the facility as it is loaded with IT equipment.

The Silicon Valley data center built by a large colocation provider achieved a 1.28 PUE at 100 percent design load, significantly exceeding the minimum energy performance of 10 percent >ASHRAE; which we estimate to be ~ 1.5 in a temperate climate zone, and also exceeded the minimum energy performance at 25 percent load by achieving a 1.43 PUE.

The Singapore data center built by a large colocation provider achieved a 1.54 PUE at 100 percent design load, significantly exceeding the minimum energy performance of 10 percent

>ASHRAE; which we estimate to be ~ 2.00 in a hot, humid climate zone, and also exceeded the minimum energy performance at 25 percent load by achieving a 1.9 PUE.

The EPC included a requirement to include the electrical losses from the power transformation and distribution systems in a data center and to also include the associated heat rejection losses in the data center cooling load.

Each of the respondents indicated that this requirement was also important because typically it takes several years or more before the data center gets to its peak design load and that depending upon the electrical power system redundancy level of N+1 or 2N that these losses are significant, especially below 50 percent UPS and PDU load levels.

However, since the USGBC LEED requirement is based upon the 100 percent design load the electrical transformation and distribution systems as designed in the past operated less efficiently during the initial build-out phase of the data center.

By requiring their designer to model the UPS and PDU systems performance at part load, they indicated that they needed to change their standard electrical design to better match the low IT power load requirements and operate more efficiently at low loads.

By using a combination of modular UPS systems and more efficient electrical redundancy designs they were able to still achieve high UPS efficiency even at low loads, albeit at higher first cost.

The requirement to also commission the data center electrical systems at these part load levels was also indicated by the respondents as being extremely valuable to their design team to validate the actual power transformation and distribution efficiency as well as to the operations team to correlate the on-going performance of the facility as it is loaded with IT equipment.

In the EPC the points weighting was changed to make the energy and atmosphere; and water efficiency requirements much more significant than the other environmental aspects of the USGBC LEED 2009 rating system such as Sustainable Sites and IEQ.

Each of the respondents indicated that these weighting changes made the EPC much more applicable for data centers due to the high energy intensity and water use for heat rejection and 24x7 operations vs. commercial buildings.

They also indicated that this required their design team to focus on these elements of the data center design and that it also made it significantly more difficult to attain the highest level of EPC certification for a data center as compared to using the USGBC LEED 2009 checklist. However they all indicated that the EPC weighting was fair and was much more meaningful to a data center developer and operator and strongly agreed that the USGBC should consider adopting a similar weighting system moving forward.

The EPC included a requirement to include real-time PUE monitoring as a pre-requisite, and provided significant points for enhanced sub-metering of cooling and electrical systems efficiency and environmental conditions in the data center.

Each of the respondents indicated that the requirement to measure real-time PUE was not difficult and was included in their base design without hesitation. They agreed that as a minimum this should be required for all new data centers and that without it there is no easy way to validate their cooling and power distribution systems efficiency of the data center.

Each respondent also indicated that they included mechanical and electrical system level sub-metering in their designs and were encouraged to do so by the EPC even though it was not included in the USGBC LEED 2009 N.C. requirements.

They also indicated that by including real-time metering of the their central plant cooling tons production and kW/ton refrigeration efficiency, air handling systems delta T and data center environmental temperature and relative humidity conditions enabled them to both validate the data center design and operation, and in one case provide real-time matching of cooling delivered to IT equipment demand resulting in improved energy efficiency of the cooling system.

4.3 Task 2.3 Research related to use of air economizers

A literature review identified that there are a number of variables which influence gaseous contamination's impact on IT equipment. This includes: gas types, mixtures of gases, combinations of gas concentrations, catalytic gases, temperature and humidity. In addition the IT industry is constantly evolving resulting in differing feature sizes, materials, and other features. For example, in 2006 the rules for materials used in electronics changed causing lead solder-based materials to be phased out and replaced in some cases with silver-based materials. Combinations of these variables make finding a single, simple multivariate root cause difficult.

The common way to determine the gaseous-caused corrosion risk in data centers is the "reactivity monitoring" method described in ANSI/ISA-71.04-1985. This method exposes a copper Corrosion Classification Coupon (CCC) to the environment for a month or more and analyzes the copper corrosion product thickness using cathodic/electrolytic reduction to classify the environment into one of four severity levels.

Using the CCC method containing copper and silver coupons strips, corrosion data was obtained for 19 data center sites. This data in general showed that copper corrosion rates were within industry accepted limits but there were some high corrosion rates for silver. One site in CA had high silver corrosion rates. In investigating the effects of contamination on the IT equipment, no centers reported equipment failures due to contamination.

The findings were summarized in more detail and reported in Appendix C.

4.4 Task 2.4 Modular data center equipment evaluations

Energy efficiency testing and evaluation of eleven different devices used for cooling computer equipment was completed in March 2010. The goal of the project was to investigate the energy performance of these products relative to each other and to current practice. Close coupled cooling is a term given to this category of cooling devices as the cooling is provided by heat exchangers located very near the computer equipment. In some designs the cooling and computer equipment is contained within a single rack sized enclosure. The heat transfer design varied, some used a low pressure liquid refrigerant that transferred heat from the cooling air to cold water supplied by the building. Other designs used air to transfer heat to water supplied by the building through a coil.

For comparison purposes the "Sensible Coefficient of Performance" (SCOP) metric identified in ASHRAE Standard 127-(2007) was used along with a metric developed specifically for this project termed "Chill-Off Energy Efficiency" (COEE) . Performance was tested over a range of different temperatures of cooling water and air provided to the computer equipment. The cooling infrastructure energy is accounted for in some results.

The results show all devices were effective in cooling the computer equipment with better energy performance than standard practice. The devices using an air to water or air to liquid refrigerant heat exchanger without additional fans at the back of the computer equipment rack (passive rear door coolers) showed a slight energy efficiency advantage. Rear door coolers that used liquid refrigerant as the cooling fluid had the best efficiency compared to other passive rear door devices due to the small pumping energy required for the refrigerant to cooling water pumping for the heat transfer unit. Some devices appeared to have difficulty controlling their fan speed resulting in more energy used than necessary to keep pace with the computer equipment air flow.

Systems were evaluated for energy use and thermal performance for varying lengths of time and for various temperatures of chilled water in order to determine performance at elevated temperatures.

The findings were presented at the Silicon Valley Leadership Data Center Summit in November, 2010, and a full report is in Appendix D.

4.5 Task 2.5 Demonstration of alternative cooling

This demonstration consisted of an innovative alternative cooling scheme, not yet commercially available at the time of the evaluation. This technology directly cools hot electronic components using conduction and convection rather than relying on air movement provided by fans in the IT equipment. Heat is transferred from the surface of the hot components to a specially designed plate at the lid of the servers where liquid refrigerant is used to remove the heat. The refrigerant is pumped through the cooling assembly by means of a cooling distribution unit (CDU) which includes a pump and a heat exchanger to a normal building chilled water system which rejects the heat to the atmosphere.

This cooling design removes the majority of the heat and allows removal of fans normally found inside the IT equipment. This design demonstrated IT equipment fan energy savings of approximately 10-12 percent in addition to the fan energy of the infrastructure fans that would have been used to transfer the heat to computer room air conditioners or the outside environment.

In addition, the project demonstrated that cooling can be effective with relatively high temperature liquid - opening the possibility of very efficient warmer water cooling that could be provided without the use of compressors. Figure 2 shows the relative performance of the units that were evaluated. For further explanation see the full report in Appendix E.

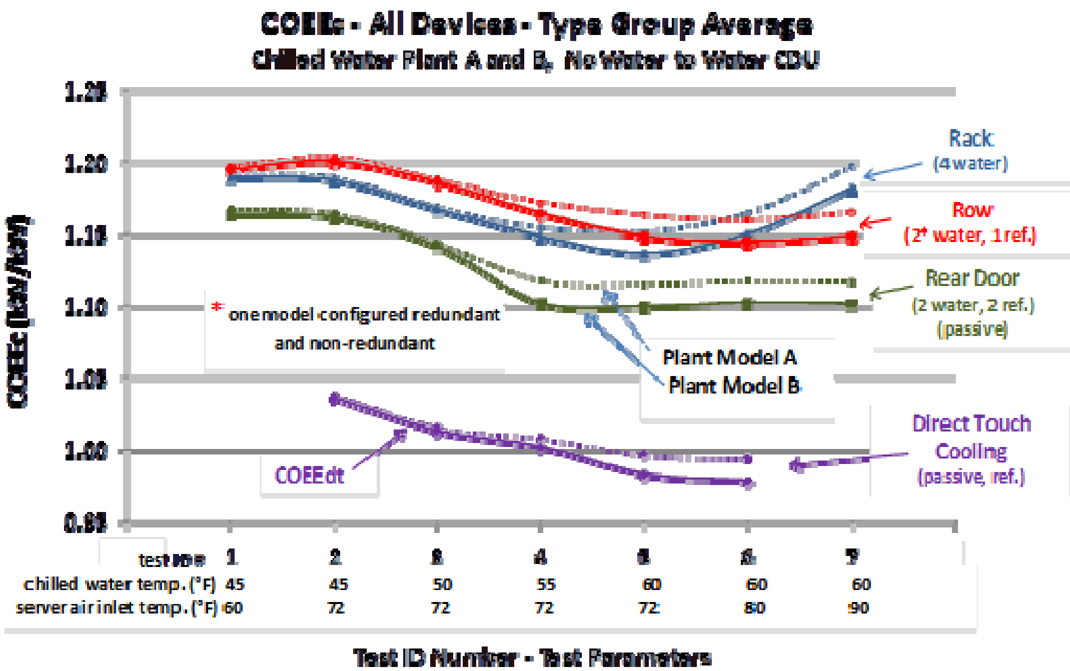

Figure 2: COEEc – All Devices – Type Group Average

The results were presented at the SVLG Data Center Summit in November, 2010, the "High Density Data Centers" Class at the PG&E Pacific Energy Center on April 6th 2011, through an ASHRAE conference paper and presentation, and a full report is included in Appendix E.

4.6 Task 2.6 Demonstration of DC Power for data centers

This demonstration at UC San Diego highlighted how DC power could be deployed to achieve energy savings, improve reliability, and eventually lower capital cost for the electrical distribution chain. In addition, there were also DC powered data center installations at Syracuse University and at Duke Energy which helped to reinforce and promote this technology. The industry partners that we worked with helped to obtain agreement on the voltage to be used (380V.) and this is being adopted at other DC power installations in the US, Europe, and Japan. There is a unique opportunity to standardize on this voltage worldwide.

During this demonstration there were also products developed that will help speed adoption of the technology. DC connectors which allow hot swapping of power supplies were developed by Anderson Power Products and they were UL certified. Delta Products Corporation and IBM have developed DC power supplies and offer them for sale. Emerson Electric and Validus DC offer rectifiers for this market and a further positive sign was that Validus DC was acquired by The ABB Group, a world-wide supplier of electrical distribution equipment.

The Emerge Alliance is a growing non-profit organization that is actively promoting the use of DC power for commercial buildings applications and has embraced the 380V DC power distribution for data center applications. This group is leading the US participation in standards development for DC power.

There were no operational issues identified from the use of DC power throughout the duration of the project at UC San Diego. The DC power installation continued operations past the completion of this project. Below in Figure 3 is a graph of AC and DC rack power that was monitored however it is difficult to draw conclusions on relative efficiency from this data.

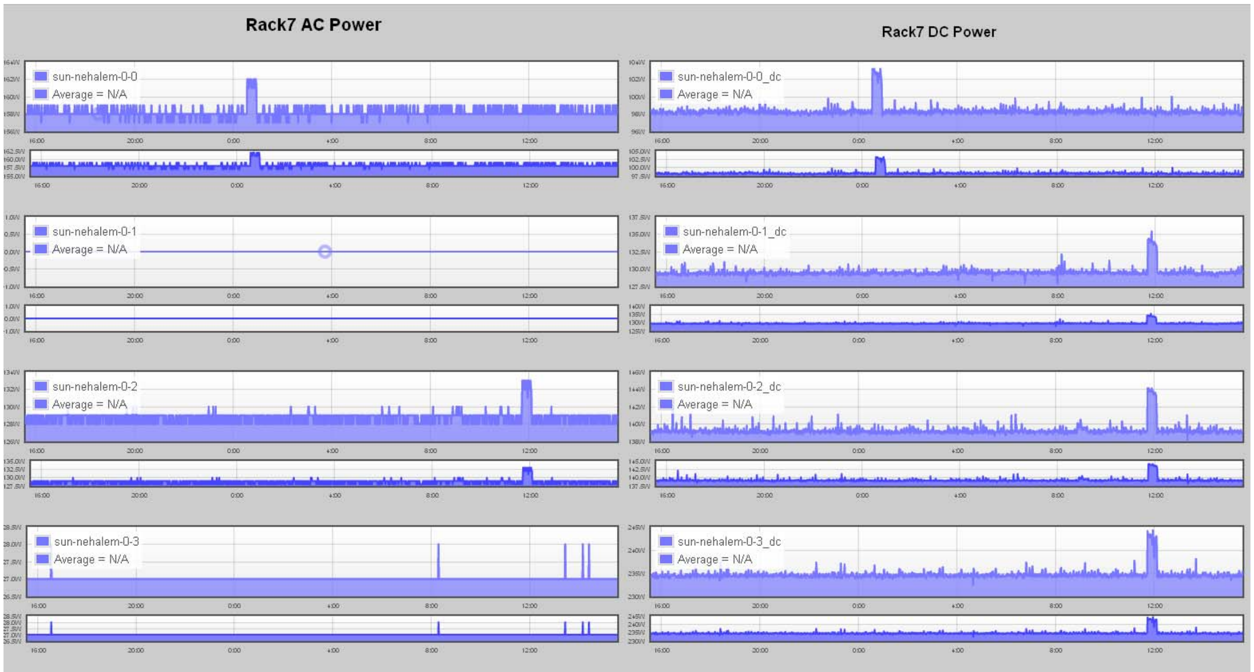

Figure 3: AC DC Rack Power

The efficiency of the rectifier used in the demonstration was measured by the Electric Power Research Institute (EPRI) and is show below in Figure 4.

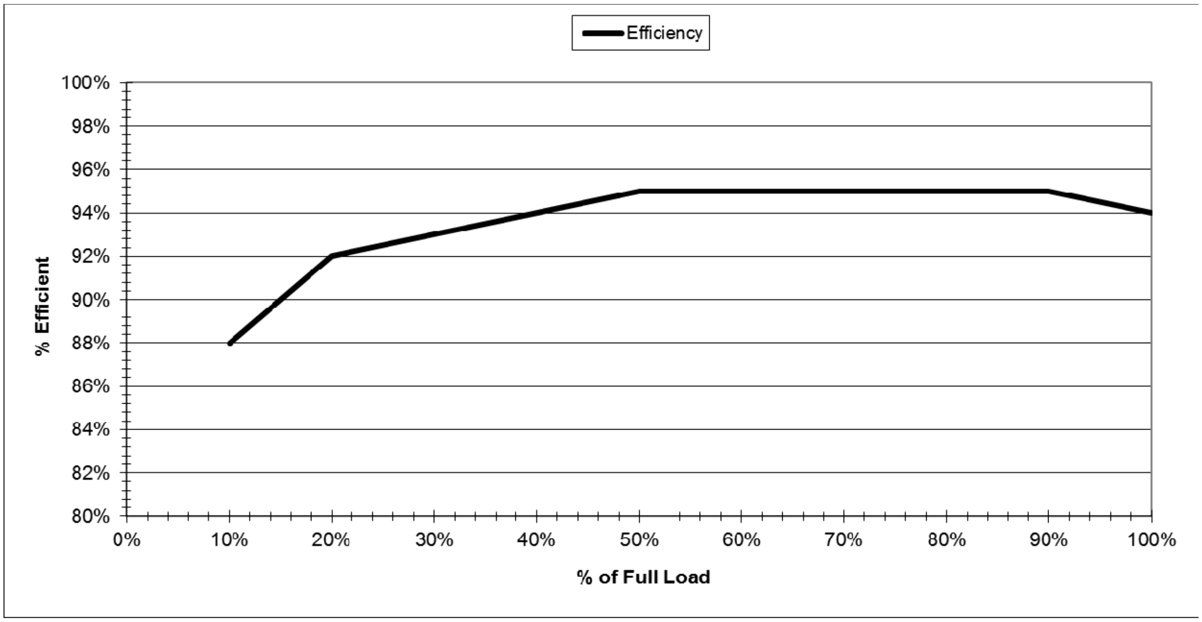

Figure 4: Efficiency Comparison

A direct comparison of the efficiency of the AC and DC systems was not possible due to the time and budget constraints of the project. It is recommended that these efficiencies be studied through a future research activity.

The demonstration was presented at the Silicon Valley Leadership Data Center Summit held at Brocade in October 2010.

Appendix F contains various photos, the SVLG presentation, and information on the rectifier testing that was conducted by EPRI.

4.7 Task 2.7 Technology Transfer

Technology transfer activities publicized the findings from this project and utilized as many channels of communication as possible, with efforts tailored for distinct target audiences, in order to reach the largest number of stakeholders. This included:

- An extensive website where detailed technical information is presented and continuously updated and maintained
- Participation in the Silicon Valley Leadership Data Center Summits
- ASHRAE presentations
- Data Center Conference presentations – Data Center Dynamics, the Green Grid, Teledata
- White papers
- Journal articles
- Workshops with industry
- Collaboration with Data Center industry associations and professional societies

- Utility workshops/training in SMUD, PG&E, and SCE territories
- Individual requests for information
- Interaction with PIER and SVLG
- Industry press releases

Chapter 5: Conclusions

Data center energy growth continues even through the economic slowdown which began in 2008. The rate of growth may have slowed due to economic forces and some improvement in adoption of best practices but it is clear that the reliance on digital technology is increasing and further efforts to find more efficient solutions to IT equipment, the infrastructure that supports it, and software should intensify.

A key conclusion from this project is that the ability to demonstrate and publically share information about new or underutilized technologies helps to accelerate the adoption. Specifically, the SVLG data center summit activities have enabled hundreds of data center professionals to see how their peers were able to implement cost effective and innovative energy saving techniques. Such demonstrations give much needed assurance to the risk adverse data center industry who otherwise would be reluctant to try new, energy saving approaches. The demonstrations also have developed a "competitive spirit" where many companies want to be perceived as leading the industry in developing new solutions. Since many of the Silicon Valley Leadership Group companies are high-tech suppliers many of them participate in other Industry Associations such as the Green Grid and ASHRAE which can influence energy performance in the sector. There is also a compounding effect with these suppliers able to influence a large market consisting of their customers. Large numbers of high-tech professionals attended the SVLG Data Center Summits (over 500 in 2010)

The proposed LEED™ criteria for existing data center facilities developed for the US Green Building Council's consideration could have a positive impact on data center energy and water efficiency. Although the USGBC is unlikely to adopt all of the proposed criteria, any adoption of the proposed weighting of points will help influence the data center market. Proposed criteria developed in this project were peer reviewed by all of the major data center organizations and this should provide substantial credibility to the USGBC reviewers.

More work needs to be done to determine whether gaseous contamination in data centers is a major concern. Many variables can influence corrosion rates due to various gases or combination of gases making it difficult to test all of the combinations. Our study was unable to obtain any failure data to confirm whether there are large numbers of failures occurring. Where we did place testing coupons, in various locations, we did not find correlation to copper corrosion rates and silver corrosion rates. Generally the corrosion levels were within acceptable limits for copper and inconclusive overall. Anecdotal evidence from IT manufacturers and companies advocating gas phase filtration indicates that they have seen failures in polluted areas in developing countries.

Comparison of commercially available modular cooling systems used to cool racks of computers showed that such cooling devices were much more efficient than standard practice. By containing and managing airflow so as to cool it near its source is shown to be a more efficient practice. The systems tested all performed well from a thermal and energy perspective. While this is true of the devices tested, the same principles can be employed in other configurations perhaps resulting in lower cost solutions.

Interest in powering data centers with DC Power continues to grow. Throughout the course of the DC power demonstration at UC San Diego a number of positive developments occurred. Interest in the use of DC power in data centers continues to grow. While there continue to be barriers to its adoption, demonstrations and pilot installations help to overcome them. This demonstration at UC San Diego successfully showed how DC power could be deployed to achieve energy savings, improve reliability, and eventually lower capital cost for the electrical distribution chain. Additional installations in the US, Europe and Japan are building credibility.

Technology transfer is an important element in delivering the lessons learned through research and demonstrations. Through use of various communication channels (e.g. websites, workshops, training programs, and industry contact) a large number of high-tech building stakeholders were reached. Numerous training and outreach workshops given at various venues in California reached a large number of data center professionals and utility representatives.

The research and demonstrations conducted under this project confirmed that there are numerous energy efficiency strategies that can improve the efficiency of data center facilities.

5.1 Recommendations

Demonstration projects continue to be an effective in reaching large numbers of data center professionals. In the risk adverse world of data center operations it is important to show how new technologies can support reliable operations while saving energy. The SVLG data center summit has been particularly effective because most of the major High-tech firms are headquartered in Silicon Valley and want to be seen as leading the industry.

As energy has become a larger focus, there is a healthy competition developing to see which firms are perceived as supporting sustainability goals including use of clean energy sources and through energy efficiency. Public Interest Research, Development, and Demonstrations have been shown to accelerate market acceptance by encouraging High-Tech companies to adopt and endorse best practices and new technologies. Once the broader market understands the technology and its benefit, they are more inclined to adopt it. For this reason, continued participation in the Silicon Valley Leadership Group demonstration program should occur.

It is recommended that PIER continue to support research and demonstrations related to this market as the market is growing and energy savings potential is high. The market is continually evolving and it is an appropriate role for Public Goods Programs to help move the market towards continuous energy efficiency improvement. Collaboration should continue with major Industry organizations such as the Silicon Valley Leadership Group to accelerate the adoption of energy efficient strategies and technologies.

The research opportunities identified in the original PIER research roadmap should be reviewed and updated. It has been approximately eight years since the roadmap was developed and with the rapid pace of high-tech innovation and evolution, there will be new efficiency opportunities that rise to the surface. Recommendations from this project generally continue to be in line with the original roadmaps' recommendations however the data center energy research roadmap should be updated due to the rapid evolution in the sector. Specific recommendations include:

- Establish a High-tech Buildings Collaborative Research activity similar to California's Demand Response Center to accelerate progress in this area and leverage PIER activities with other potential funders.
- Continue market transformation activities to promote best practices and emerging technologies.
- Best practices should continue to be developed or refined and publicized through demonstrations and case studies for training and in order to promote wider adoption.
- New and emerging data center cooling solutions such as the Clustered Systems solution should be evaluated in order to determine their energy implications. Demonstrations or incentives should be explored in order to encourage use of solutions that offer the most efficient operation such as encouraging liquid cooling that can utilize high temperature liquids.
- Direct use of DC power in data centers continues to hold promise for substantial energy savings in data centers while improving reliability and reducing capital cost. Continued encouragement of the technology through participation in DC industry standards development, demonstrations and incentives could speed its adoption. Further studying the efficiencies of the UC San Diego installation in a future project is recommended.

REFERENCES

A complete list of publications produced under this project, as well as reports referencing the work can be found here: http://hightech.lbl.gov/library.html

"High-Performance Data Centers – a Research Roadmap", Lawrence Berkeley National Laboratory Report No. 53483

Rumsey Engineers and Lawrence Berkeley National Laboratory. 2006. "High Performance Data Centers: A Design Guideline Sourcebook." Part of the Energy Design Resources collection.

GLOSSARY

Specific terms and acronyms used throughout this work statement are defined as follows:

ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
BTU	British Thermal Unit
Cfm	cubic feet per minute, a measure of volumetric flow rate
Commission	California Energy Commission
CPR	Critical Project Review
DOE	United States Department of Energy
HVAC	Heating, ventilation, and air conditioning system
IT	Information Technology
KW	Kilowatt (1000 Watts)
LBNL	Lawrence Berkeley National Laboratory
MW	Megawatt ($1x10^6$ Watt)
PAC	Project Advisory Committee
PIER	Public Interest Energy Research program (Commission)
RD&D	Research, Development and Demonstration
T	Temperature, measured in degrees Celsius or Fahrenheit
TC	Technical Committee
TWh	Terrawatt hour ($1x10^9$ kWh)
UPS	Uninterruptible Power Supply

Appendix A

Appendix Number	Contract Task Number	Task Description	Deliverable Description
A	2.1	SVLG – PIER Data Center Summit	• Company attendees
B	2.2	LEED™ type criteria for existing data centers	• Proposed Environmental Performance Criteria • Application Manual
C	2.3	Encouraging Air Economizers	• Contamination Report • Indoor Air Conference Paper • Indoor Air Conference presentation
D	2.4	Evaluate Modular Cooling	• Report • SVLG presentation
E	2.5	Demonstration of Alternative Cooling	• Report • ASHRAE Conference Paper • ASHRAE Presentation
F	2.6	Demonstration of DC power	• SVLG demonstration Presentation • Photos • Rectifier Test Procedure and results
G	2.7	Technology Transfer	• Workshop presentations
H	N/A	Research Roadmap	Data Center Research Roadmap